A MODERN CYCLONE HARBOUR FOR ESCORT CLASS TUGS IN NORTH-WEST AUSTRALIA

by

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ABSTRACT

This paper describes the design and layout of the marine facilities associated with the recently constructed Hunt Point Tug Harbour in Port Hedland. Port Hedland is located 1,322km north of Perth in Western Australia. The DMS latitude:longitude coordinates for the harbour are 20°18'14"S, 118°34'11"E. It is Australia's highest tonnage port and one of the largest iron ore loading ports in the world. Port Hedland is situated on one of the most cyclone affected stretches of coastline of the southern hemisphere with a tidal range of 7.5m.

The key design challenges addressed in the design were:

1. A requirement for post-cyclone operability up to and including a 500 years ARI cyclone event.
2. Safe egress from the tugs following completion of the cyclone mooring procedure in up to gale force winds (35 knots).
3. A design storm tide (including an allowance for 0.4m sea level rise) of 9.2m above LAT.
4. Cyclone berths catering for *RAstar 85* Escort Tugs with maximum displacement 1175t.
5. Minimise the environmental footprint and any regret capital expenditure associated with the potential future expansion of the harbour.

The resulting harbour design has met with approval from all stakeholders including the operations personnel.

1. INTRODUCTION

BHP identified a requirement to increase their towage services in Port Hedland. The strategic aims achieved through the recently completed harbour include:

- Mitigate the significant risk associated with the potential grounding of a vessel blocking the shipping channel which is 42km in length, tidally constrained and uni-directional.
- Provide new state-of-the-art tug berths to support the increased towage requirements associated with the planned future expansion of the iron-ore export operations at the port.
- Reduce the cyclone related disruption to port operations.

The new facility at Hunt Point has been designed to accommodate eight (8) new escort class tugs. Located behind an existing seawall, the environmental footprint, impact on recreation at the adjacent public beach and the requirement for marine based construction plant have been minimised. Four (4)

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berthing pontoons are located within the harbour catering for two (2) tugs at each berth. To provide for improved operability of the berths, the following features have been included on each pontoon:

- Fixed rotating access brows at two locations to allow bow-in and bow-out operational mooring of the tugs.
- Cyclone mooring line reels.
- Mooring line hangers.
- 1.8m wide gangways (of maximum 1:4 slope at LAT) providing a zero-step access to each pontoon through the full 7.49m tide range.
- Along-side cyclone mooring arrangement capable of surviving cyclones up to 500 years ARI (compared with a four-point cyclone mooring arrangement used elsewhere within Port Hedland).
- Mooring line snap-back guards for safe egress after mooring the tugs in pre-cyclonic conditions.
- Shore power, compressed air, drinking water and fire-water provided via the gangway.

In addition to the eight (8) tug berths, a pontoon for small boats is provided in the south-west corner of the harbour, as are navigation aids (including day-night lead marks designed in accordance with IALA specifications), revetments and other associated shoreside facilities.

2. TUG HARBOUR LOCATION AND LAYOUT

The Hunt Point Tug Harbour location was selected as the preferred location as it provides a number of benefits including:

- No increase in environmental footprint.
- Least energetic conditions within the lease boundary enabling a safer, less complex cyclone mooring design.
- Located within an existing seawall allows for shelter to be achieved with minimum effort.

The general arrangement of the harbour can be seen in Figure 1.

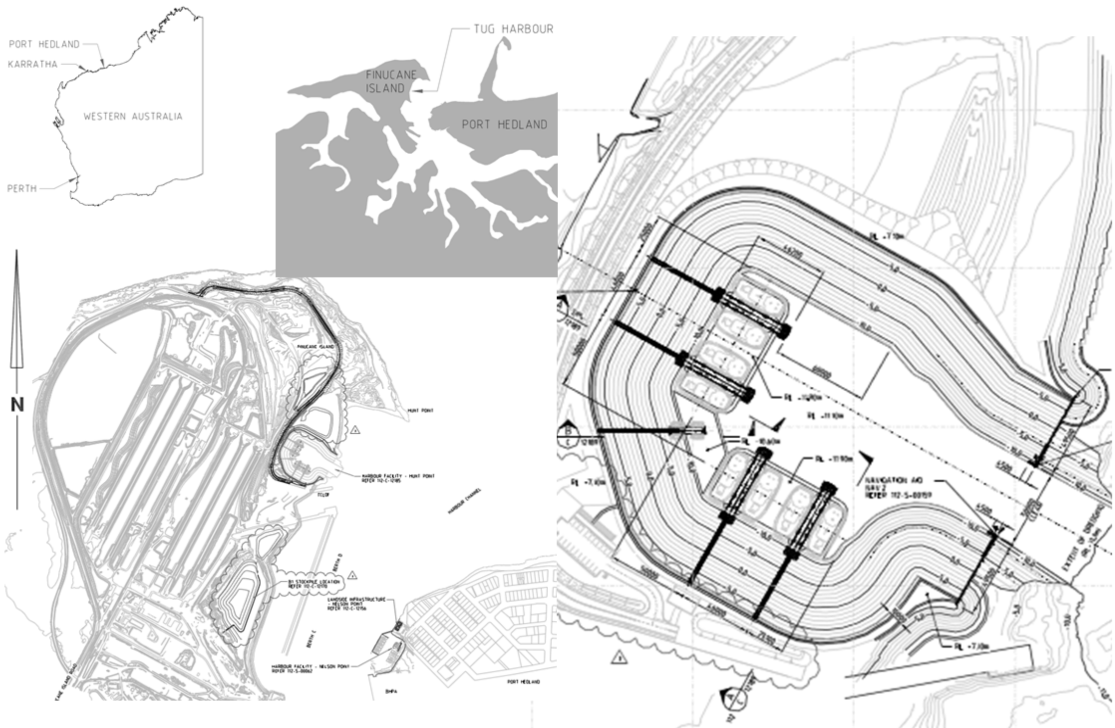

Figure 1: General arrangement and locality of the harbour

Part of an existing sea wall was removed to create the 50m wide (at the toe of the entrance channel) entrance to the facility. Two 45m long piled sea-walls are located either side of the entrance to the harbour to protect the heads of the revetments in severe weather conditions and minimise wave penetration into the harbour.

2.1 Operational and Cyclone Berthing Arrangement

A cyclone mooring arrangement alongside a pontoon has been adopted in lieu of the four-point arrangement used elsewhere in the port. This provides the following benefits:

- Reduced per-berth footprint.
- Safe for access to shore following completion of cyclone mooring procedure.
- Reduced cyclone mooring procedural complexity.
- Simpler tide-following mooring point details integrated into the pontoons.

The facilities provided within the Hunt Point Tug Harbour satisfy the requirements of operational and cyclone berths for eight (8) escort tugs. This is provided via four (4) 52m long, 5.85m wide pontoons. The pontoons are arranged so that two are parallel to the adjacent coastline (NNE-SSW) behind the causeway to the south of the entrance and two lie WNW-ESE on the far side of the harbour. Each of the four pontoons has been designed to be capable of berthing two (2) of the escort tugs. The operational mooring berths for four (4) crew transfer vessels are provided by a 21.6m long by 4.5m wide pontoon running E-W.

Each tug pontoon has been designed to allow the tugs to moor either bow-in or bow-out during non-cyclonic periods. For cyclone mooring, the tugs are required to moor bow-out. The crew transfer pontoon is for operational use only and is not required to moor boats during cyclonic conditions.

The mooring of the vessels alongside the pontoon prior to the onset of gale force winds (pre-cyclonic conditions) enables landside access via the pontoon and access gangways for the crew to go ashore after completing the cyclone mooring procedure.

The fendering system comprises two twin air-block fenders per tug (four per pontoon). Low friction facing is used on a 2.4m wide fender panel to increase the contact width on the tug sponson. The air-block fenders provide a low reaction at small deflections making them ideal for use on the pontoons and with the tug hull geometry. The size of the air-block fenders is governed by the design cyclonic conditions. The energy absorption requirements during normal and abnormal berthing are significantly lower than those for peak cyclone events.

3. DESIGN INPUT AND DECISIONS

The following are key inputs affecting the tug harbour design. The final design was the result of carefully balancing the requirements for safety, operability, navigability and minimising the environmental footprint on one hand, while ensuring cyclone survivability, durability, and constructability at the same time.

3.1 Geometric considerations

To keep the footprint of the tug harbour substantially within the existing sea-wall, all critical dimensions needed to be kept to safe minimums; in part due to the presence of a site boundary to the west of the harbour limiting the space available to construct the harbour. The dimensions minimised included:

- Berth pocket width and length
- Berth spacing
- Proximity of the tugs to the revetment
- Swing basin geometry
- Length of the gangways

- Size of the pontoons

The slope of the batters was also maximised, however, due to the dredged material fill in the upper layers, this could not be made steeper than 1:2.75.

3.2 Operability

For operability, the following minimum clearances were provided:

- 50m wide entrance
- 100m x 100m swing basin for manoeuvring
- 5m clearance to the revetment at LAT
- 2m clearance either side of vessels on final approach to berth when a tug is moored at the adjacent pontoon.

3.3 Geotechnical

The geotechnical investigations indicated five (5) general layers. They were:

- Fill (dredge spoil) – cohesive and granular from (0m to +11m Australian Height Datum – hereafter AHD)
- Holocene deposits – beach sands and estuarine sediments (between -5m and 0m AHD)
- Coastal deposits – uncemented (1m layer around -5m AHD)
- Upper red beds – stiff clay (below -5m AHD)
- Lower red beds – very stiff clay (below -15m AHD)
- Calcareous conglomerate – high strength rock (below -25m AHD)

Note that the levels indicated are only approximate and significant variation occurs across the site. The excavation of the harbour extended through the top layers down to the red beds – 'in the dry.' The piles which restrained the pontoons were subject to lateral loads and they founded in the lower red beds, which is a stiff clay. Initial soil springs used in the dynamic simulation were determined in accordance with ISO 19902 methods for stiff clay with and without the effects of scour.

Cyclic loading was of concern following the work of Reese et al. (1975)[6] This is because under cyclic lateral loads, the strength of stiff clays once loaded past a threshold diminishes rapidly. This work was based on loading a pile to the same peak load 100 times. It showed:

1. Deterioration in stiffness of the upper levels once loaded past a peak (up to which reasonably elastic behaviour was observed.
2. If subject to a load which exceeded the peak load it had been previously subject to, no significant reduction in stiffness or load carrying capacity was observed. I.e. a large once-off load should not be treated as a representative cyclic load.

A representative cyclic load was generated by reviewing the bending moment occurring at sea bed level in the dynamic simulation for the largest 100 pile load events. Further details are presented at the end of Section 4.

3.4 Meteorological / oceanographic data

The most significant challenge to the design of cyclone moorings in Port Hedland is the significant tidal range and related peak storm wave conditions. Two distinct sets of waves affect the site. Within the harbour, these are:

[6] L.C. Reese, W.R. Cox and F.D. Koop, 'Field Testing and Analysis of Laterally Loaded Piles in Stiff Clay', *Proc. 5th Annual Offshore Technology Conf.*, OTC 2312, Houston, Texas, April 1975

- Waves that enter Port Hedland through the shipping channel and which are caused by tropical cyclones that pass the north-west shelf area (H_s = 2m, T_p = 7s to 11.5s).
- Waves that are caused by cyclonic winds blowing from the southerly sector across the relatively short fetch within the harbour (H_s = 1.4m, T_p = 4.5s)

There is a strong correlation between the wave heights entering the harbour and the water level. Several ambient extreme wave conditions and pre-cyclonic conditions affecting the site were also investigated to confirm operability of the pontoons.

Table 1 gives the tidal planes at the site.

Tidal plane		Level (mCD)
Highest astronomical tide	HAT	+7.49m
Mean high water springs	MHWS	+6.66m
Mean high water neap tide	MHWN	+4.60m
Mean sea level	MSL	+3.93m
Australian height datum	AHD	+3.902m
Mean low water neap tide	MLWN	+3.26m
Mean low water springs	MLWS	+1.19m
Lowest astronomical tide	LAT	0.00m

Table 1: Tidal planes at the Hunt Point tug harbour

The 500 years Average Recurrence Interval (ARI) was adopted for the design. Design wave conditions in the harbour were developed based on previous work associated with the Port Hedland Outer Harbour Project which included the development of a synthetic Monte Carlo based 10,000 years cyclone track database.

3.5 Design vessel description

The berths were designed to accommodate the following RAstar 85 Class escort tugs designed by Robert Allan Ltd. The tugs provide an 85t bollard pull for escort operations via two azimuthing stern drives (3m diameter props) powered by two 2,550kW (@1800rpm) engines. A cyclone mooring post with a 306t SWL is provided aft for fixing the stern lines and the 400HP main winch of the vessel has a braking capacity of 250t.

The design vessel has the following particulars.

Length	L	34.94m
Beam (width)	B	14.75m
Maximum displaced mass	M_d	1175t
Maximum draft	D	6.18m

Table 2: Particulars of the RAstar 85 tugs

4. SIMULATION AND MODELLING APPROACH

4.1 Wave penetration modelling

Wave penetration investigations were undertaken using the MIKE-21 Boussinesq Wave (BW) model system developed by the Danish Hydraulics Institute (DHI). In addition to forming the basis for the design of the combi walls, internal and external revetments, and rock armour, the modelling was required to provide input to the dynamic mooring simulation. The wave data extracted for each berth included the H_{m0} (spectral definition), T_p (spectral peak period), as well as the direction spread and peakedness of the JONSWAP spectral form. A fitting function was used to extract up to four distinct wave components (frequency-direction bands), at each berth as input to the dynamic mooring simulations.

Examples of the directional spectra extracted from the model and the associated fitting are presented in Figure 2.

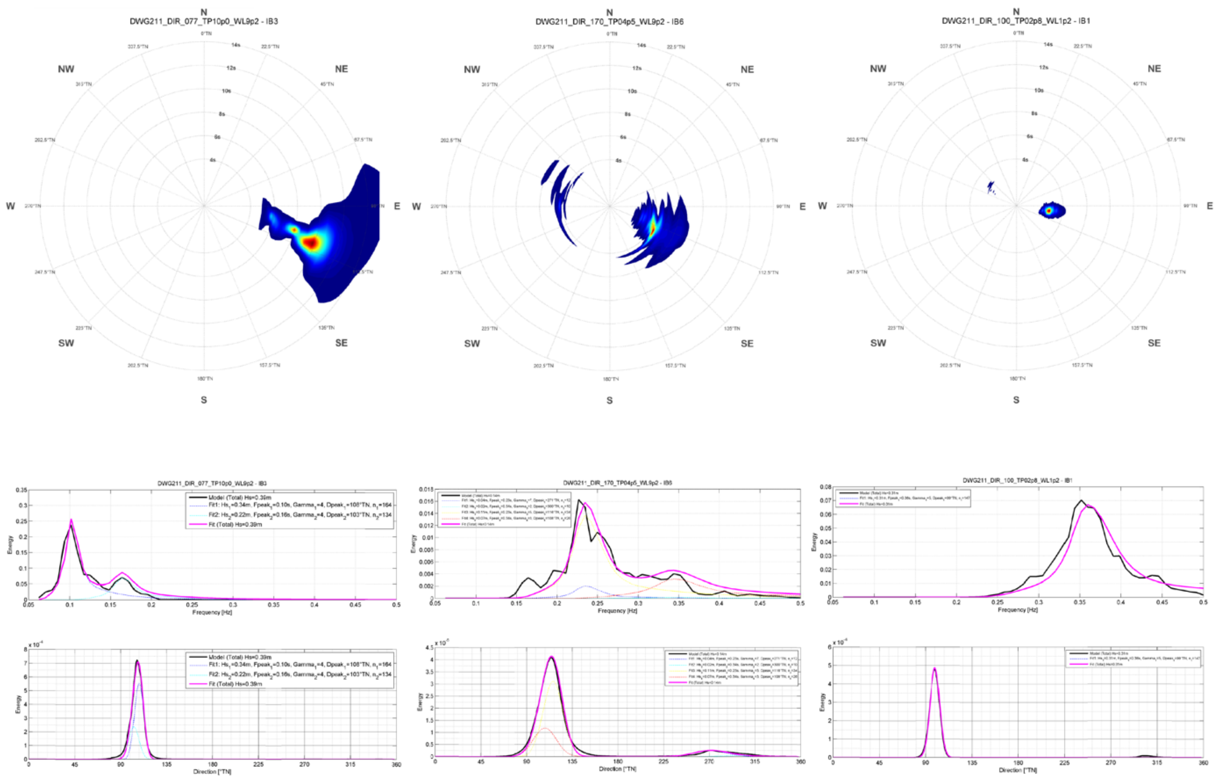

Figure 2: Directional spectra (top) for three scenarios, the associated wave spectra (black) and fit (pink) for the frequency domain (middle) and directional spread (bottom)

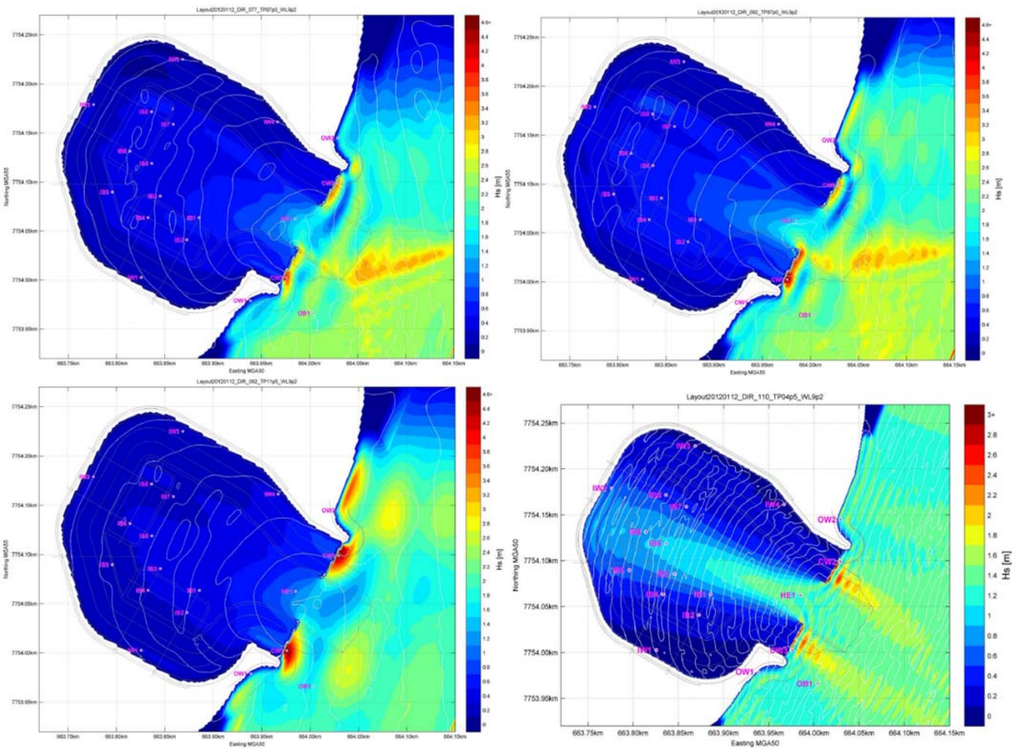

Figure 3: Example wave penetration modelling results for a 500 years ARI storm tide of 9.2m. Model boundary waves as follows: (*top left*) T_p = 7s, h_{sig} = 2m, dir = 77°TN, (*top right*) T_p = 7s, h_{sig} = 2m, dir = 92°TN, (*btm left*) T_p = 11.5s, h_{sig} = 2m, dir = 92°TN, (*btm right*) T_p = 4.5s, h_{sig} = 1.4m, dir = 110°TN

Figure 3 indicates significant attenuation of the longer period waves with the use of vertical piled seawalls at the entrance. The walls are integrated with the existing seawall by way of roundheads comprising rock infill and an external layer of 3t rock. Wave run-up and overtopping rates were also calculated for the revetment design in accordance with EurOtop.

4.2 Dynamic mooring simulation

A hydrodynamic analysis using ANSYS AQWA-Line was conducted to calculate the response of the tugs and the pontoon with interaction effects between the multi-bodies taken into account. Response amplitude operators (RAO's), quadratic transfer functions (QTF's), added mass, damping and hydrostatic stiffness were then input to the time domain software OrcaFlex. This was used to generate the 6 degree of freedom (DOF) motions of the tugs and the pontoon subject to the various incident design wind and wave conditions, mooring line and fender reactions. Due to the large tides, and high correlation between tide level and wave heights, a 1-hour simulation time frame (the maximum duration of peak tide at which the design waves can penetrate into the harbour) was completed for each of the four berths subject to a total of 20 design incident wave conditions. The resultant 80 cases were run through nine iterations of the design.

Yokohama pneumatic ship-ship type fenders were adopted initially based on initial simulations using monochromatic design waves. However, upon completion of the full set of simulations, some peaks exceeding various design limits resulted in several iterations trying to balance the control of vessel motions with the peak line loads and fender reactions on the vessel. The design of the tugs had been completed prior to the harbour design and so there was limited scope for the modification of the tugs.

At the end of the design, a significant amount of data had been generated:

- 90 core variables were extracted from each simulation including fender reactions, line loads, vessel motions, pontoon motions, pile loads, brace loads etc.
- 20 design wave scenarios (applied to each iteration of the design)
- 4 twin-tug berths with distinct wave climates at each berth

- 360,000 time-steps (0.01s) per simulation
- 2.6Billion data points generated per design iteration
- >23Billion data points generated throughout the design

Significant effort was employed to reduce the amount of analysis using intuition. At the end of each set of simulations, the worst cases for key design criteria would be chosen for re-analysis with adjustments made to pre-tensions, fender, and line arrangements. The worst five or so cases were reasonably consistent from iteration to iteration in a general sense, i.e. cases causing generally more dynamic responses from the berth would be consistent. However, as peak loads were often caused by short periods of resonance within the system, they would often occur sporadically in a case which was not in the set of worst cases analysed at the previous design iteration.

It became apparent after the first few iterations, that while general trends could be observed and predicted with reasonable accuracy, individual peaks occurring for <<1s were very difficult to predict with certainty before all 80 combination cases had been analysed. A compounding factor was that different berths would govern for different fender properties and line geometries at each iteration as the design developed.

In the end running all 80 test cases at each design iteration progressed the design in the shortest possible time.

It is noted that, while the detailed simulation approach is becoming the state of the practice, the design approaches of yesteryear, in the vast majority of cases, continue to provide acceptable outcomes. With the dawn of the automation of the design process upon us, there will be some important questions regarding the cost-benefit of adopting complex analysis approaches. For now, the application of intuition, sound judgement and efficient operation of modern design tools remains paramount to the efficacy of the design process.

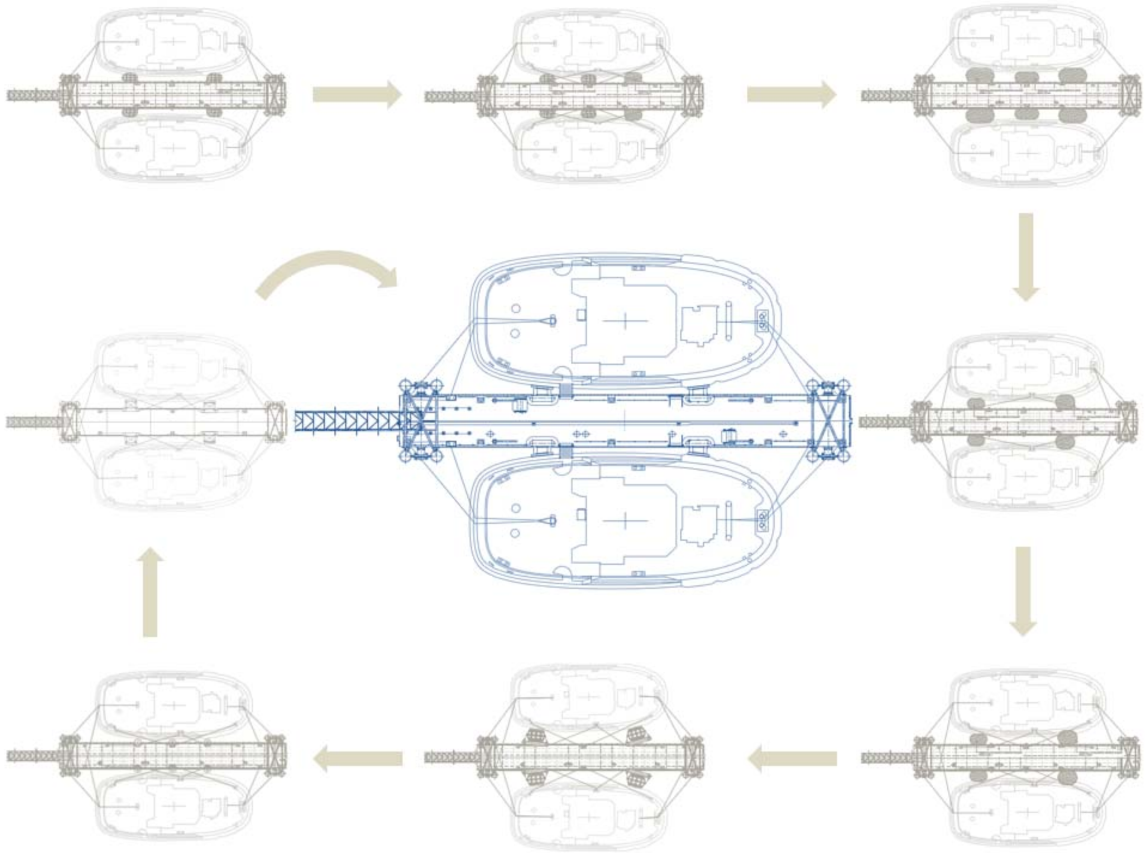

Figure 4: Design iterations leading to the final design with twin Yokohama ABF-P fenders and two head and two stern lines with 18t pretension in each line

4.3 Determining a representative cyclic load for pile design

Typically wind loads would result in cyclic loads about some non-zero average and so it is not possible to define a *load event* as a maximum load occurring between two *zero load* points. Instead, recursive maximisation was used to find significant load fluctuations that could be considered peak individual load events filtering out higher frequency fluctuations near the maximum. Upon review of the data, the best result for the simulation data was achieved with three recursive maximisations. An example is indicated in Figure 5.

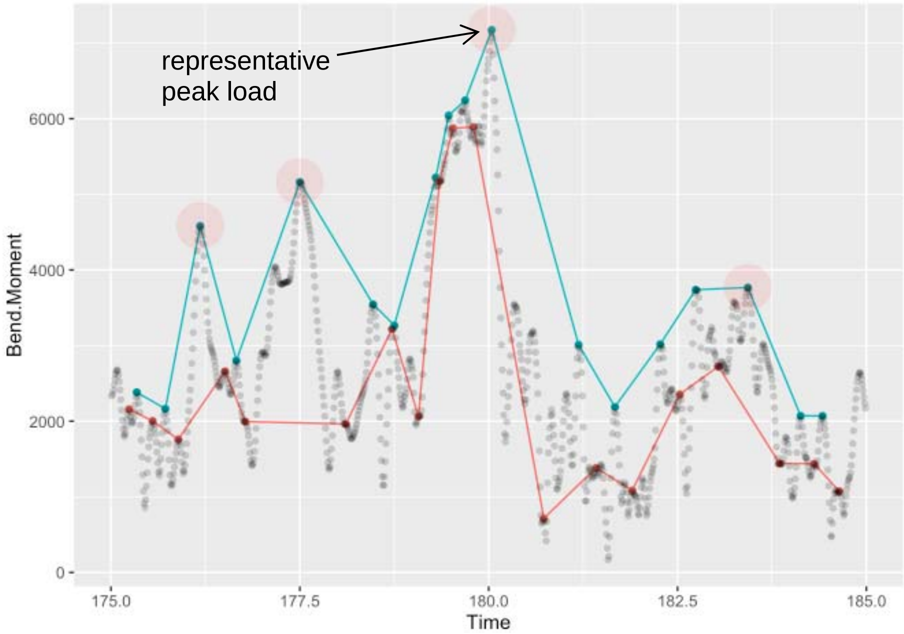

Figure 5: Cyclic load assessment – finding representative peak pile loads showing raw data (black translucent dots), and the result of three passes of recursive local maxima finding (large red translucent dots). The blue line indicates local maxima included in the second and used for the final pass and the red line represents local maxima which were reclassified as local minima in the second pass.

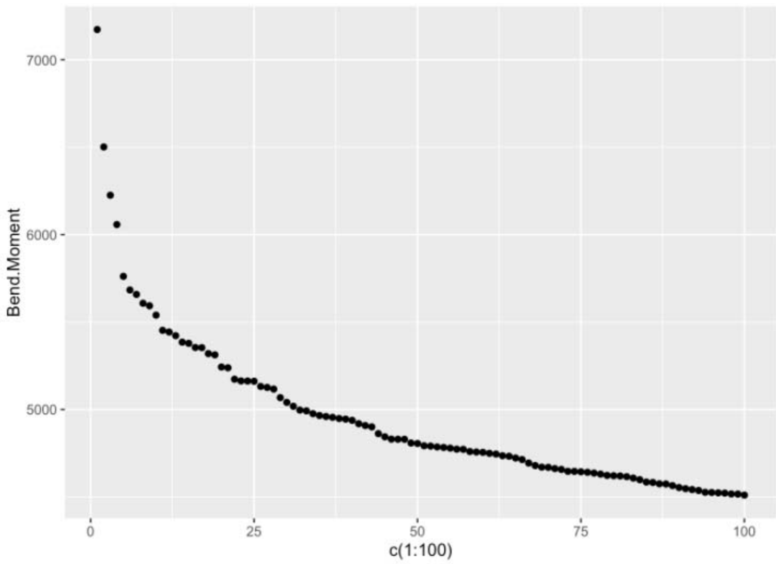

Figure 6: Top 100 *peak load* events for a pile (showing pile bending moment at sea bed level)

Upon review, for the given site and cyclic load levels, only the very upper-most embedded section of pile (~1-2m below ground level) was loaded past the peak and so the effect on the lateral capacity and deformation of the piles was negligible.

5. FENDER AND LINE SELECTION

The major innovation in respect to the mooring design came with the adoption of dual Yokohama air-block fenders. These fenders provided several benefits. The location of the load on the tug hull, which is highly contoured, could be controlled so that it was applied to the sponson on the tug (also the strongest part of the hull) and there was a significant variation in the level over which contact could occur due to the relative roll and heave of the pontoons and the tugs in a design conditions. The added benefit of this was that at low deflections, a low reaction was provided, while at large deflections, large loads were applied. This resulted in a good balance between allowing small oscillations to occur without excessive loads developing in the system on the one hand, while on the other hand effectively arresting the largest motions and preventing tugs from colliding with tugs at adjacent berths, or the revetments in extreme conditions.

While loads extracted from the simulation represent ultimate fender reactions, fenders are generally specified for operational loads with a factor on the energy for an abnormal berthing. The supports for the fenders are then designed with a load factor on the rated reaction at the rated energy to account for (among other variabilities), potential overloading of the fender. Yokohama were most helpful in providing for specific impact speeds and events extracted from the model, what the recommended maximum reactions were for the air-block fenders (beyond the rated capacity).

Similarly, the nylon double braid mooring lines provided a flexibility and associated energy absorption capacity providing the dissipation necessary for an along-side mooring.

To size the fender panel, the height of the relative position of the tugs and pontoon were extracted from the dynamic simulation and analysed to determine the range of relative heights. The following is an example of the peak load occurring at each level relative to the centre of the twin ABF fenders.

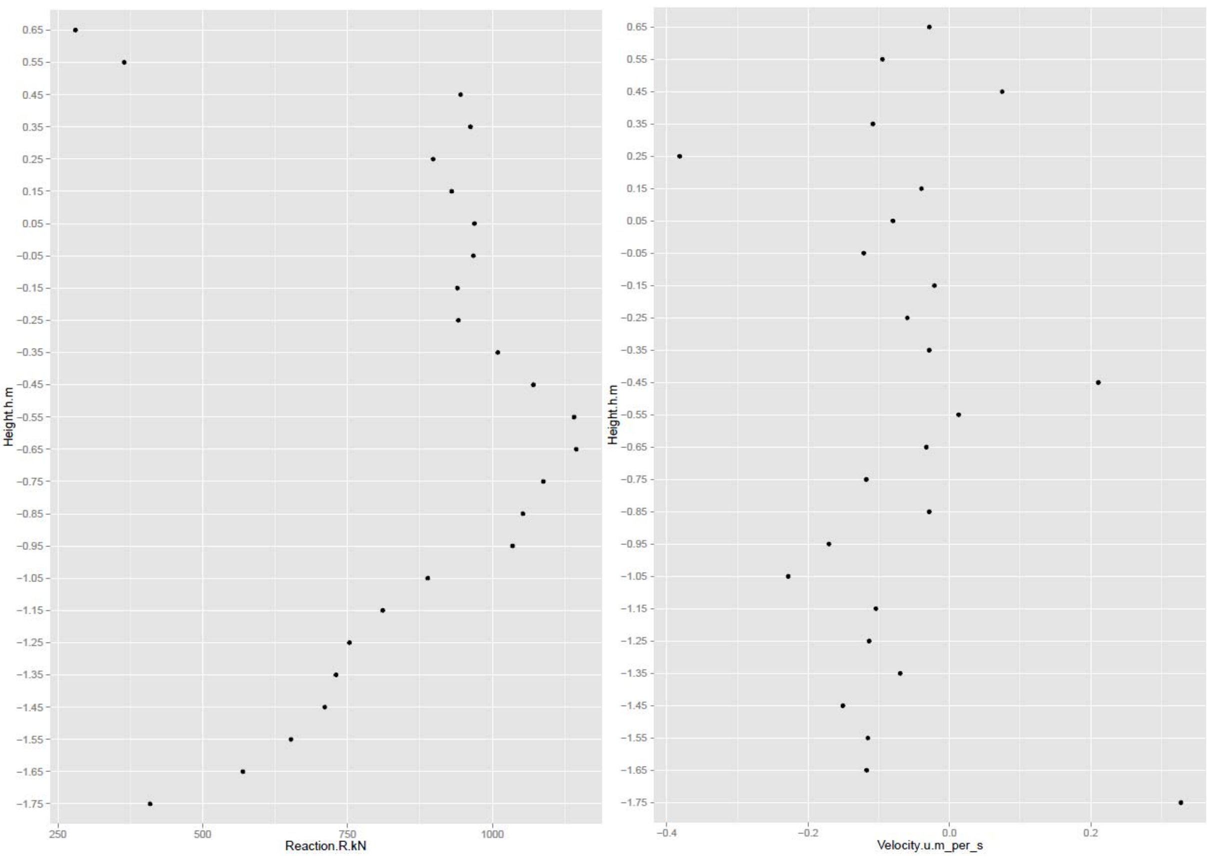

Figure 7: Peak design load varying with distance from the centre of the Yokohama twin ABF-P fenders (*left*) and associated velocity at impact (*right*)

Extracting and summarising the data in this way allows both the effects of low and high impacts to be assessed against the capacity of an individual fender, which will be taken by a single fender, as well as ensuring that the panel extends sufficiently to ensure the tug does not ride up over the fender panel nor get caught underneath. More than 115 million data points were used to create each graph.

6. OPERABILITY FEATURES

The key benefit of the adopted design is the alongside mooring in preparation for a cyclone, which allows crew to disembark safely following completion of the cyclone mooring procedure via rotating access brows provided on the pontoons. Mooring line hangers are used to minimise manual handling and maximise efficiency setting the operational mooring lines and mooring line reels are used to store and protect from UV and salt spray the cyclone mooring lines when not in use. The access brows are 1.5m wide and manually operable (<15kg load) from both the tug (using a boat hook) and the pontoon side. Snap-back guards have been provided at the end of the gangway where the tug crew must pass lines under pre-tension as they leave the pontoon after completing the cyclone mooring procedure. The features described above are shown in Figure 8.

Tugs enter the harbour and align in a swing basin within the harbour prior to entering the berths. A full-bridge simulation was completed for the facility and found that berthing was possible at all berths in pre-cyclonic conditions with tug operator training.

Figure 8: Operability features (clockwise from top left): access brow lowered, access brow raised, snapback guards, mooring line hangers, cyclone mooring line reels

6.1 Operational mooring

The following operational mooring design arrangement comprises two lines connected to bitts on the tug. The typical operational mooring is a bow-in arrangement, this maximises the distance between the main operating plant of the tug and the adjacent revetment slope. Access is provided via rotating access platforms aligned with the access at the aft of the tug. These are self-latching and manually operable by boat hook or hand so that it is possible to lower and raise the brow from either the tug side or the pontoon side.

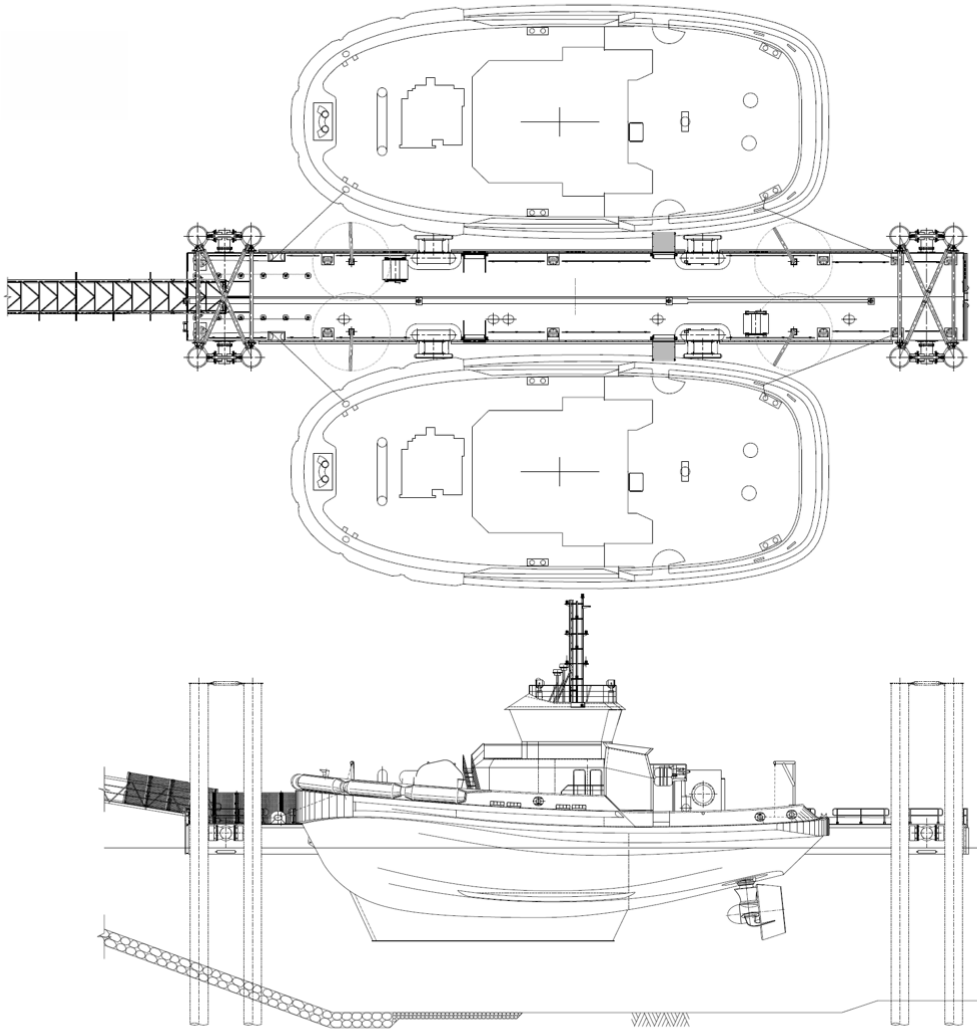

Figure 9: Operational mooring arrangement

6.2 Cyclone mooring arrangement

The cyclone mooring arrangement has the tug in the bow-out position. Each of the four (4) 88mm diameter Samson Super Strong double braid nylon mooring lines are tensioned to 180kN using the main winch on the tug. The bow-out mooring of the tug minimises the response of the vessels to waves entering through the harbour entrance in cyclone conditions. While the tension in the aft lines is relatively low (<15% MBL), it was a client requirement that snap-back guards be provided to protect the crew leaving the vessel. Access is provided by rotating access brows aligned with the aft access on the vessels. Part of the cyclone mooring procedure requires that the mooring line hangers (used for operational mooring) are locked and the brows returned to a vertical position upon disembarkation to prevent impact between these and the tug.

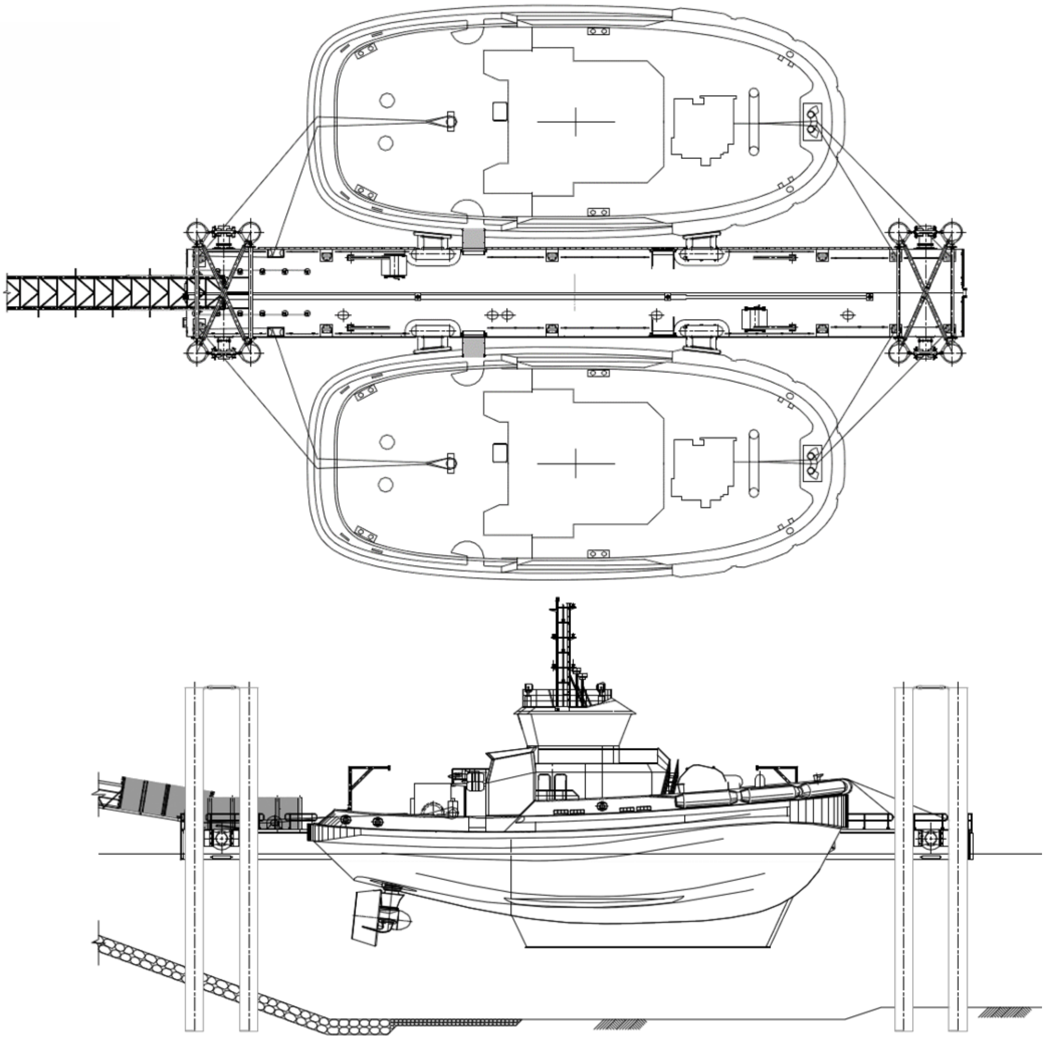

Figure 10: Cyclone mooring arrangement

6.3 Value through simplicity

The pontoon restraints and construction tolerance for the piles is achieved through pinned brace connections at the top of the piles and through extruded rubber SC and arch fenders providing contact between the MDPE coated piles and the pontoons. The MDPE coating provides superior wearing characteristics compared with steel, and the fendering units are easily accessed and simple to maintain.

A key objective of the mooring design was to avoid the use of spring lines. The use of dual head and stern lines provides redundancy in the mooring arrangement, while at the same time avoiding the operational complexity that would be introduced if crew needed to walk across spring lines when leaving the tug following completion of the cyclone mooring.

7. COMMISSIONING

One of the essential components of the cyclone mooring line – to which peak loads were determined to be quite sensitive – was the initial pretension. In the model, the pre-tension was applied in the absence of environments, and with the tug located in a neutral position, aligned centrally between the fenders.

The design initially called for the tug winch reading to be used to confirm that the correct pretension had been achieved in the system (~36t force in the winch). However, the combination of fixed-length stern lines and friction between the tug and the fendering panels resulted in significant variation with the tension in the head lines far exceeding the tension in the stern lines. This behaviour was replicated in the model and sensitivity tests were carried out to see if this would affect the behaviour of the tug. The results of the analyses showed that provided the lengths of all four lines were correct, the initial pretensions were not so important.

The challenge at this point was to get accurate measurements of all four (4) line lengths under the specified tension with the tug in the correct position alongside the pontoon. This was achieved by using four long-stroke rams which were able to tension each line to the required pretension. The test arrangement is indicated in Figure 11.

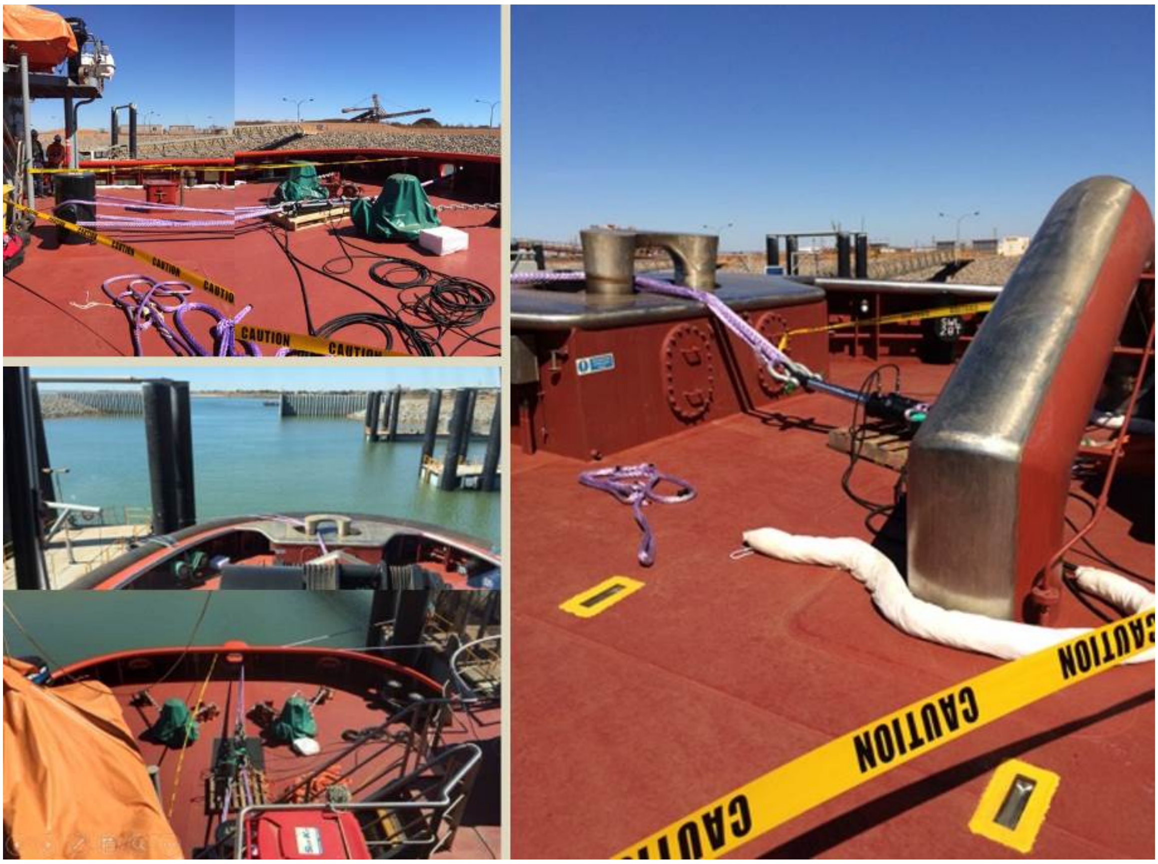

Figure 11: Making template lines

Upon completion of the measurements, lines were made up to a tight tolerance (+/- 0.2m) and the two head lines were marked where they should sit over the level wind on the winch. This allowed the repeatability in cyclone mooring procedure to be assured. This also removes the reliance on instrumentation, and a dependence on the assessment of tension in variable wind and wave conditions, changes in the initial position of the vessel or instrumentation failure.

7.1 Feedback from operations

The comments received from operations have been most positive. The tug crews indicated that they very much like the fendering and that the harbour has been *"built to last"*. And it has.

Acknowledgements

The authors would like to thank BHP and Lendlease for giving us the opportunity to be involved in the project and allowing this technical paper to be presented.

References

L.C. Reese, W.R. Cox and F.D. Koop, 'Field Testing and Analysis of Laterally Loaded Piles in Stiff Clay', *Proc. 5th Annual Offshore Technology Conf.*, OTC 2312, Houston, Texas, April 1975